



THz Research at BESSY II

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Coherent FIR Synchrotron Radiation at BESSY

- Mechanism of CSR emission
- Characterization of CSR

FIR Experimental Station

- FIR beamline port
- Martin-Puplett spectrometer
- Imaging

Application of CSR at BESSY:

- Spectroscopy
- Con-focal and near-field imaging

Summary and Outlook

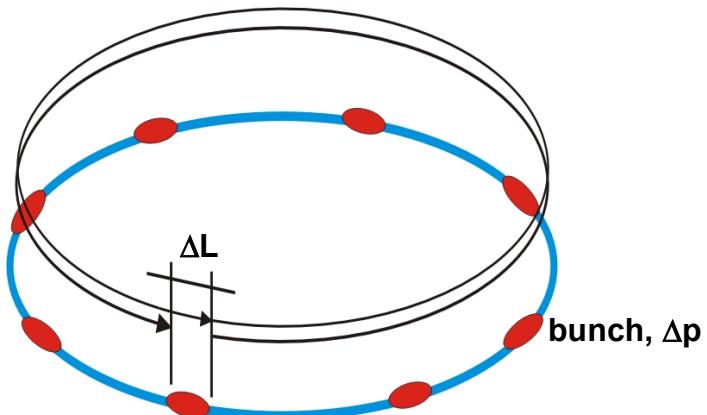




Coherent Radiation from Electron Bunches

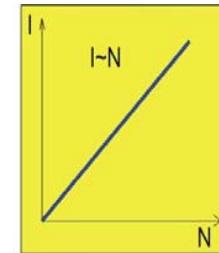
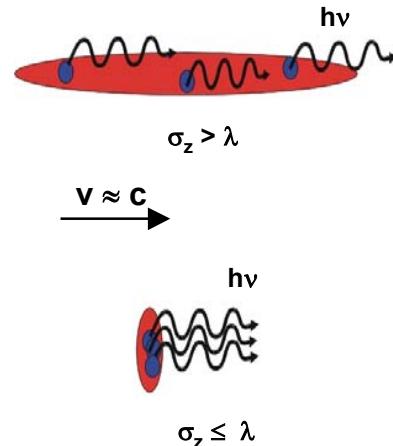


reference orbit: $L = 240$ m

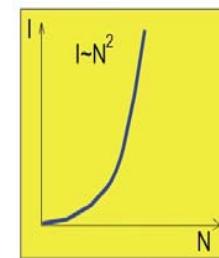


momentum compaction factor: $\Delta p/p \alpha = \Delta L/L$

longitudinal bunch length intensity vs. number of electrons



normal user optics
 $\sigma_z > 5$ mm
 $\Delta t > 35$ ps
 $\alpha = 7 \cdot 10^{-3}$



low alpha optics
 $\sigma_z \leq 1$ mm
 $\Delta t < 7$ ps
 $\alpha \approx 10^{-4}$

Dedicated Machine Mode: “Low α “ Optics at BESSY:

- Bunch shortening down to and below than the mm-range
- Emission in the FIR range is drastically enhanced





Filling the “THz Gap”

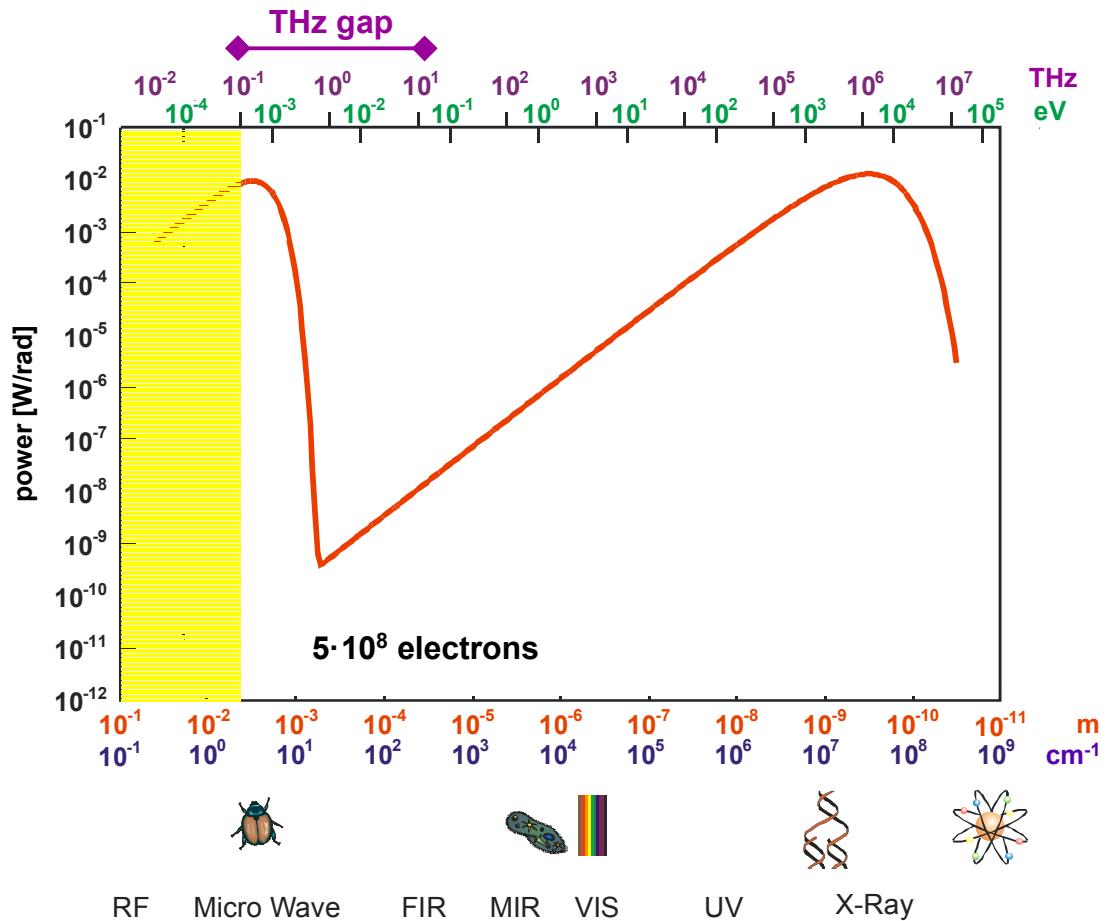


Coherent Synchrotron Radiation

N-times higher intensity
(Gaussian bunch assumed!).

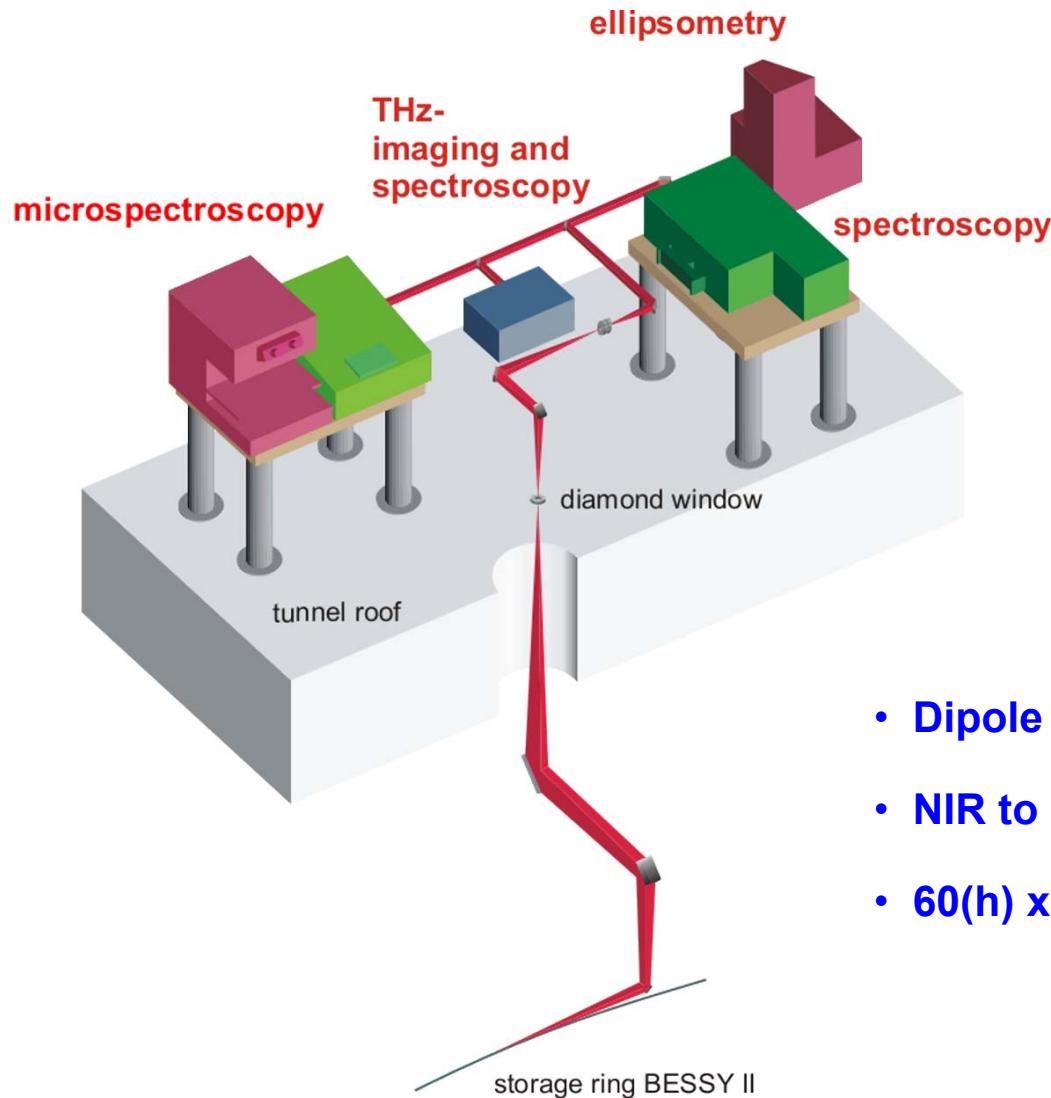
Cut-off due to shielding
effects.

Powerful source emitting in the
THz and sub-THz range.





IRIS - Infrared Beamlne at BESSY





FIR (THz) Equipment



Spectrometer:

	<i>Bruker 66/v</i>	<i>Martin-Puplett (DLR)</i>
spectral range (cm⁻¹)	2 – 600	2 - 100
beamsplitter	6µm, 50µm and 125 µm Mylar	free-standing wire grids

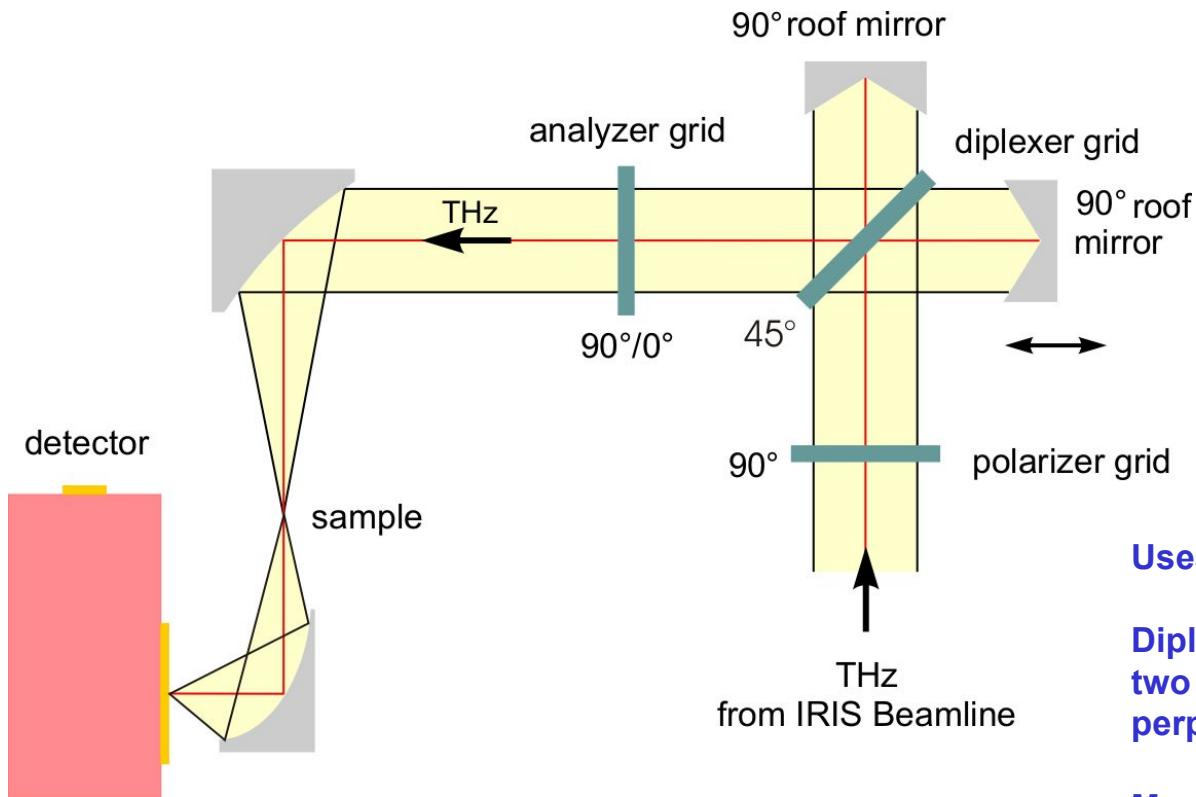
Detector:

	<i>DTGS</i>	<i>Si-Bolo 4.2 K</i>	<i>Si-Bolo 1.2 K</i>	<i>InSb HEB</i>	<i>SC HEB</i>
spectral range (cm⁻¹)	50 – 600	10 - 600	2 - 60	2 - 30	7 - 100
max. BW	1 kHz	1kHz	1kHz	1MHz	5 GHz
NEP (W/$\sqrt{\text{Hz}}$)	1e-9	1e-13	3e-15	1e-13	1e-12





Martin-Puplett FT-Spectrometer



Uses free-standing wire grid polarizer.

Diplexer grid divides beam into two linearly polarized components, perpendicular to each other.

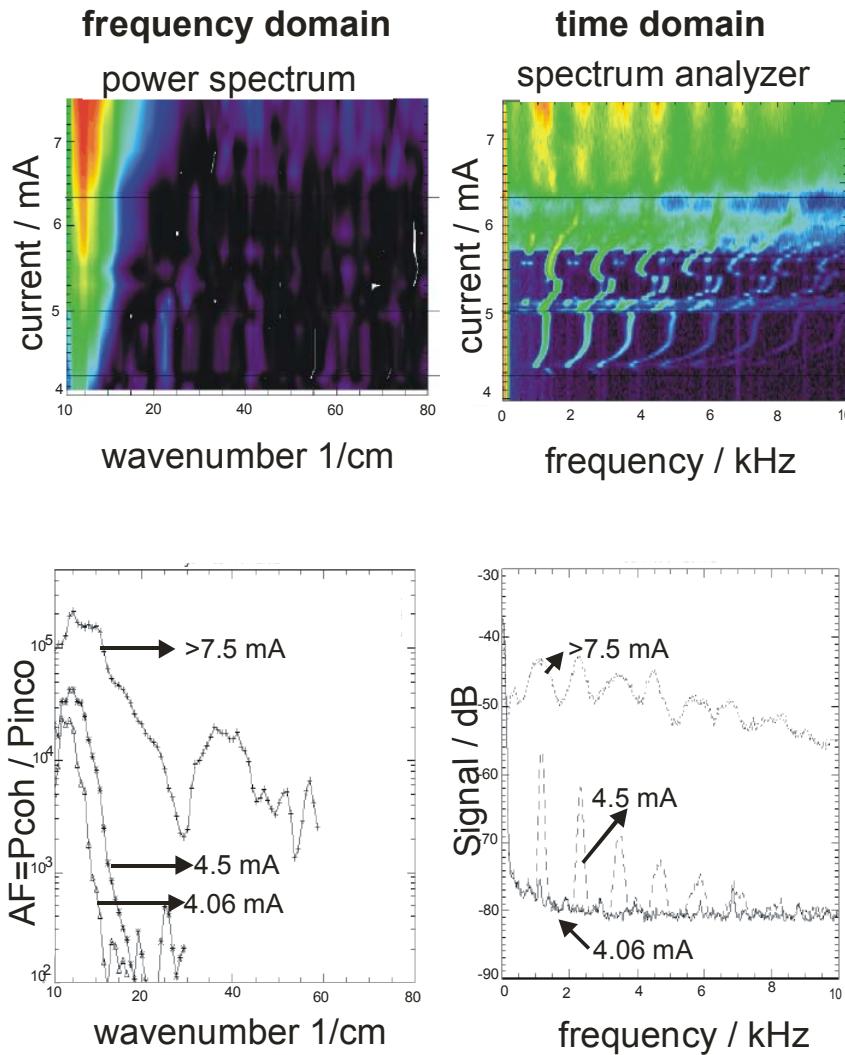
Movable mirror modulates polarization.

Interferogram is given by the intensity of the linearly polarized component behind the analyzer.





Current Dependent CSR



CSR at much higher frequencies than expected for Gaussian bunch profiles.

Present understanding:

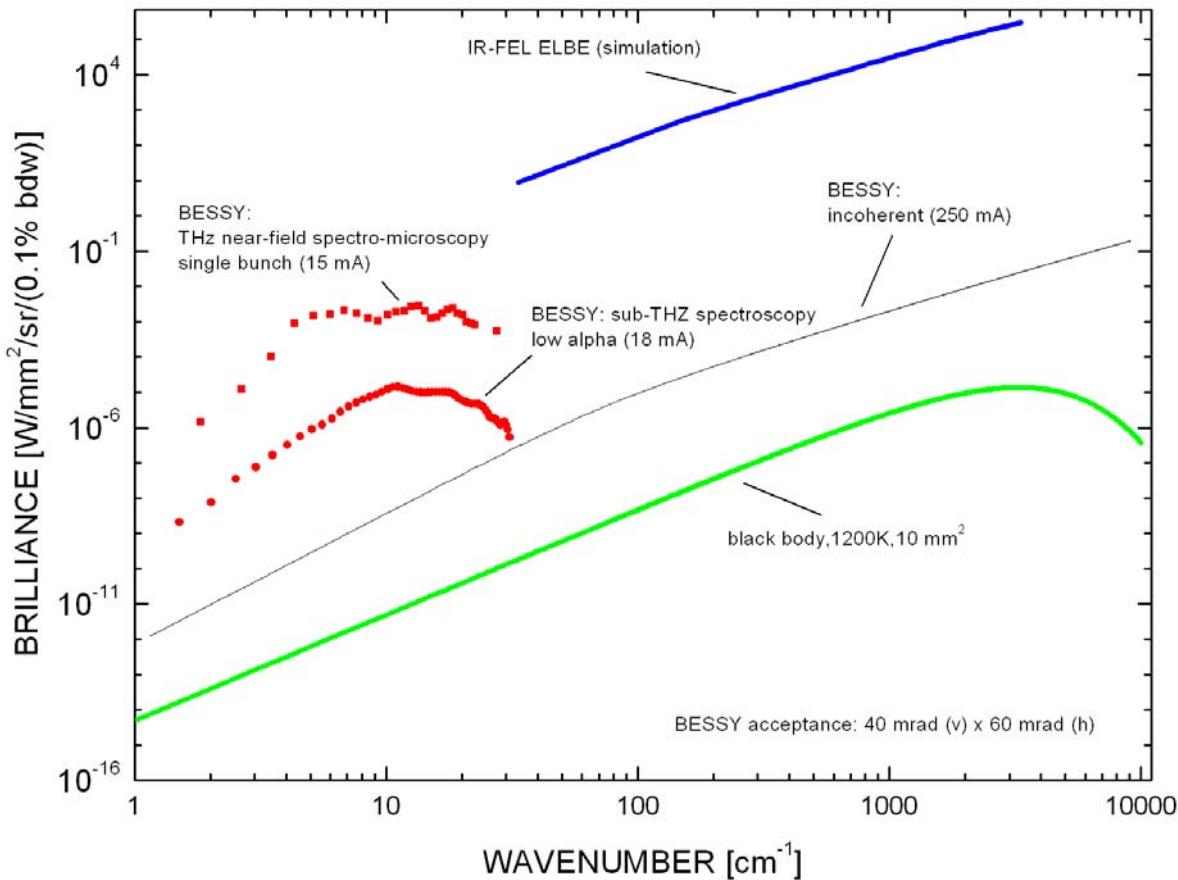
Interaction of bunch with CSR-wakefield leads to:

- a static non-Gaussian deformation of the bunch below a current threshold (Bane, Krinsky and Murphy, 1996)
→ steady-state CSR
- bursting CSR emission above a current threshold (micro-bunching, Stupakov and Heifets, 2002)
→ high power bursting CSR





Brilliant THz-Radiation at BESSY



“low α” mode

- steady-state CSR
- energy range: 2 - 30 cm⁻¹
- gain of ~10⁵

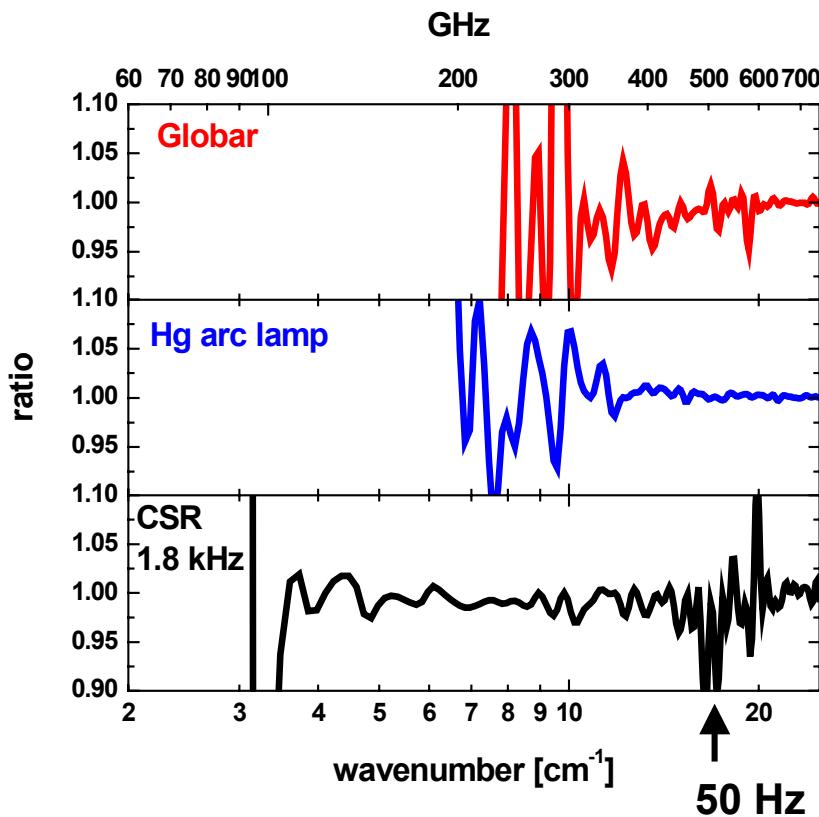
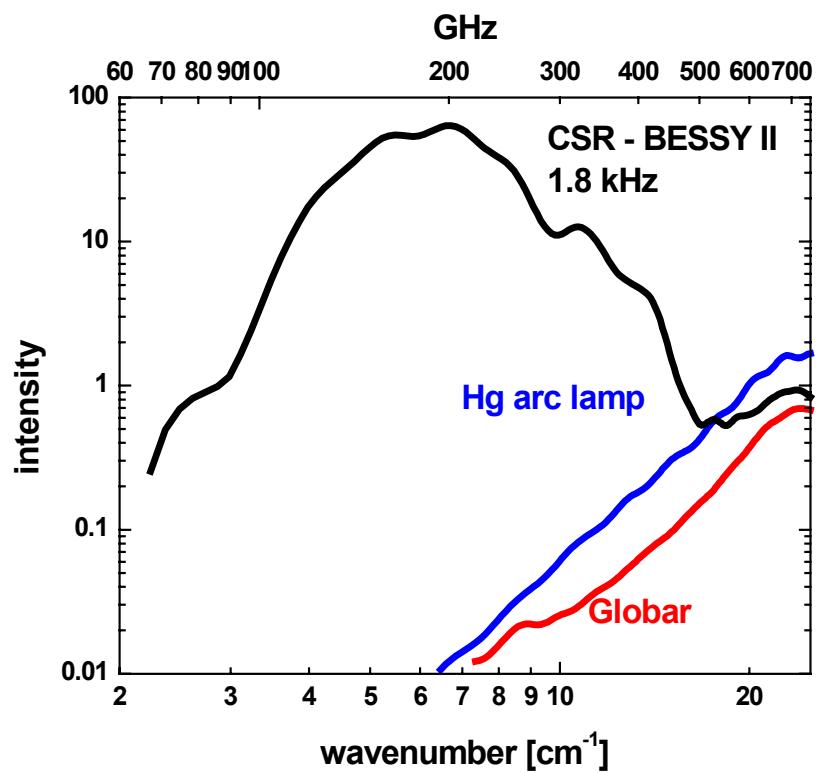
“bursting” mode

- high power CSR
- energy range: 2 - 50 cm⁻¹
- gain of ~10⁸

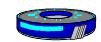




Steady-State CSR for Rapid Scan FTS

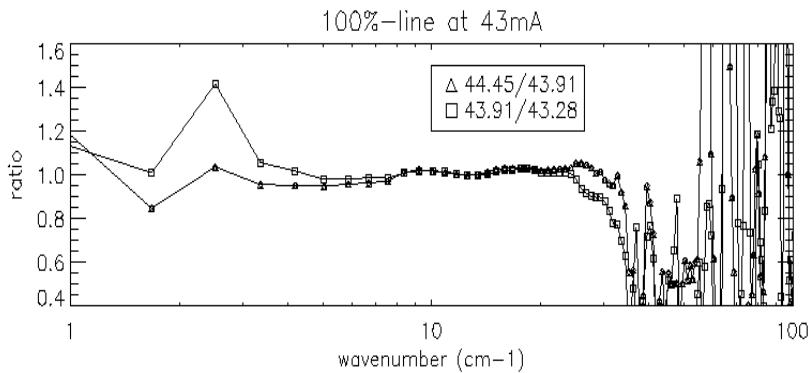
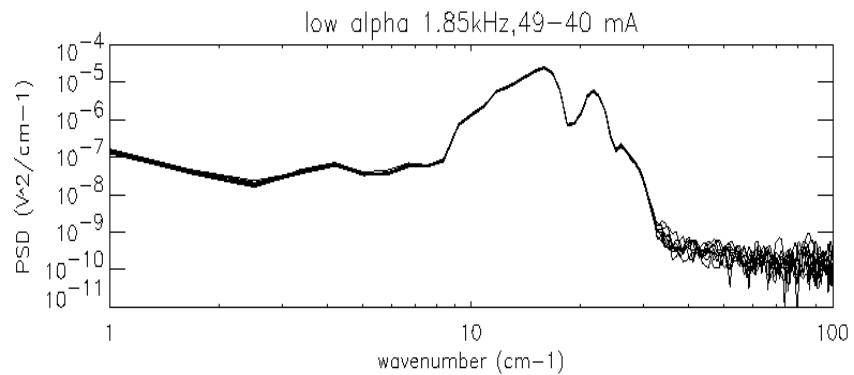
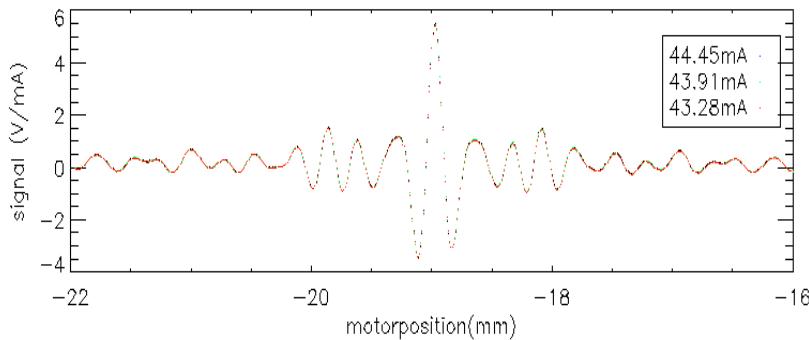


- Bruker 66/v + 1.4 K Si-bolometer (M. Martin, ALS)
- $\sim 10^3$ increase in flux over thermal source at 10 cm^{-1}
- cut-off due to shielding
- spectral noise artifacts





High Power Bursting CSR for Step-Scan FTS



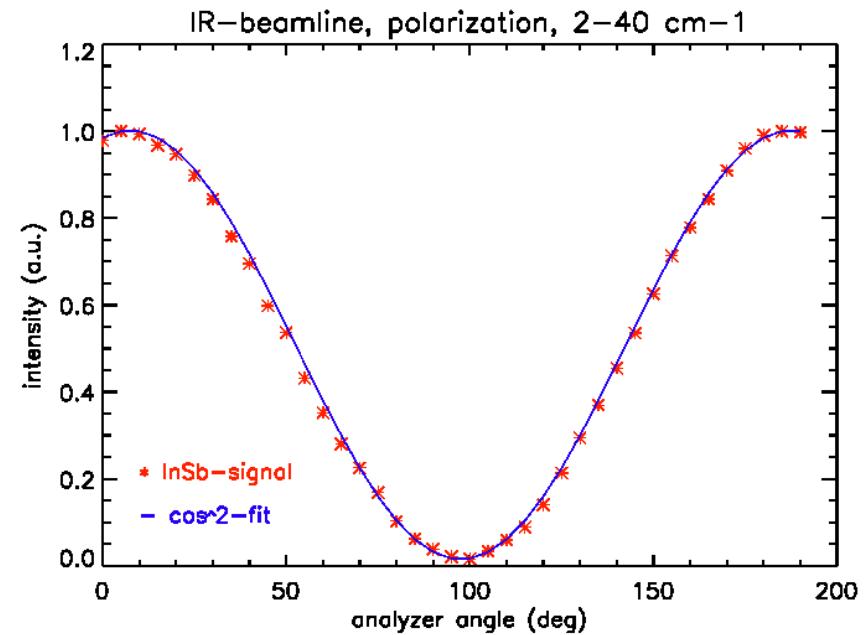
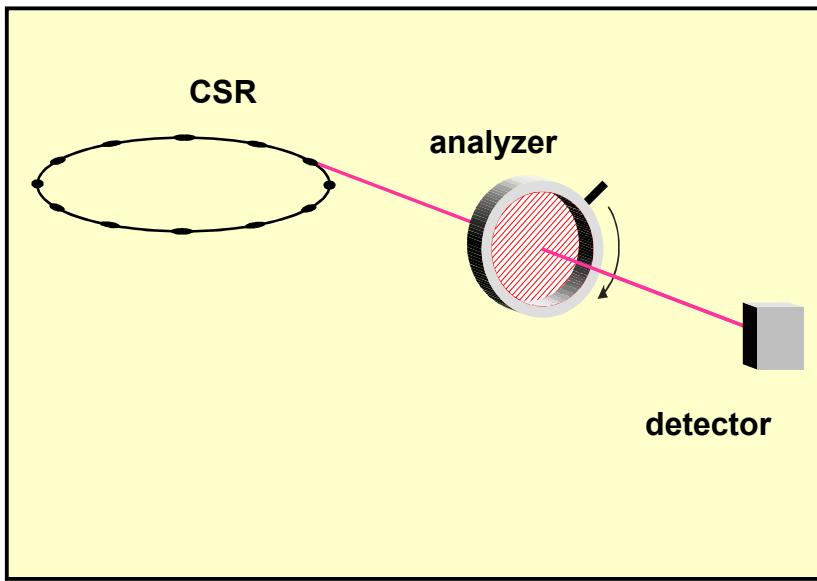
Bursting CSR is a suitable THz source for FT-spectroscopy.

- Martin-Puplett FTS (step-scan mode) + He-cooled InSb HEB
- lock-in technique (bunch revolution frequency of 1.25 MHz as reference)
- integration time of 200 ms





Polarization Characteristics of CSR



- fits to \cos^2 of the azimuth angle of the analyzer
- 99 % linearly polarized parallel to the storage ring plane

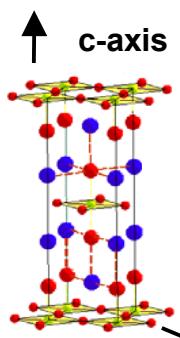
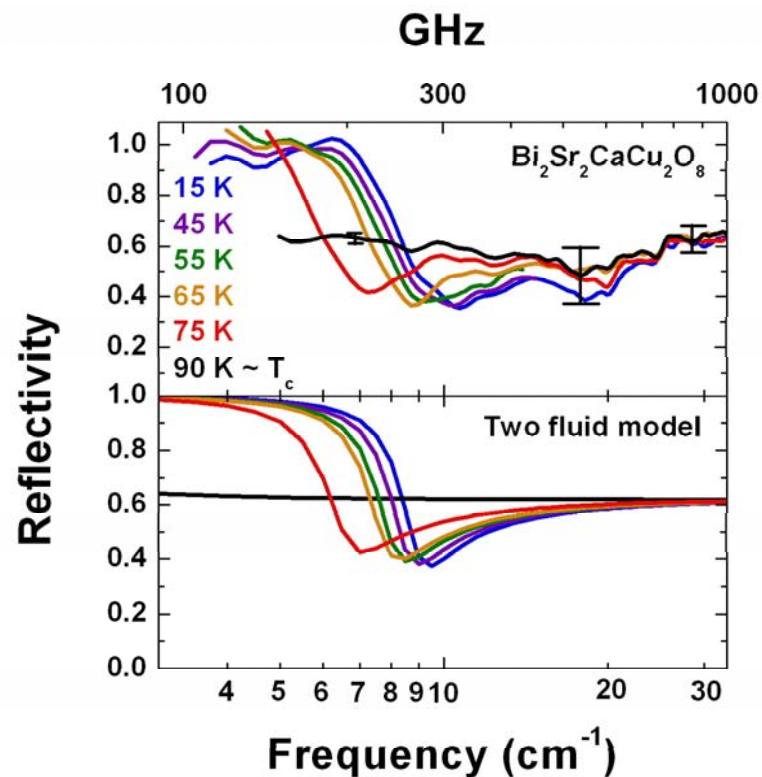
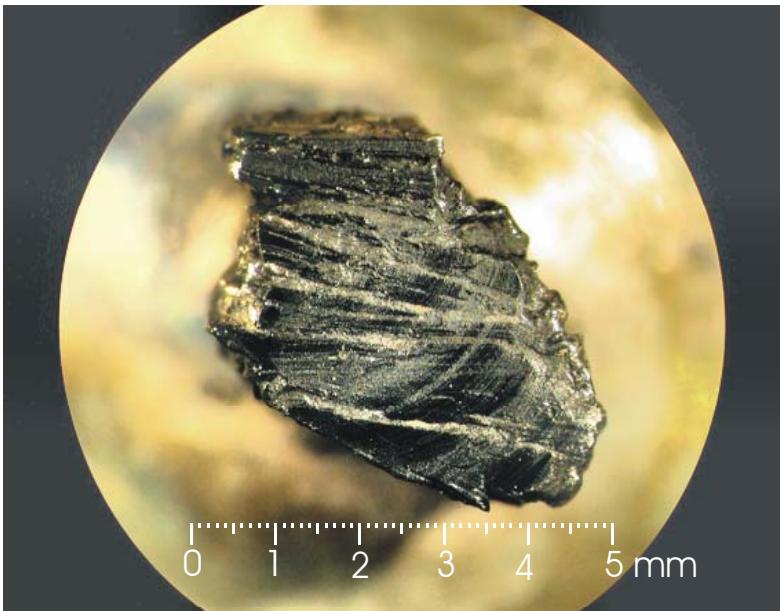




High- T_c “Cuprate” Superconductor



Optimally doped $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$



- experiment: J. Singley and M. Martin (ALS), D. Basov (UoC San Diego)
- sophisticated reflectance experiment at low temperatures with THz radiation
- JPR never observed before in optimally doped $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$

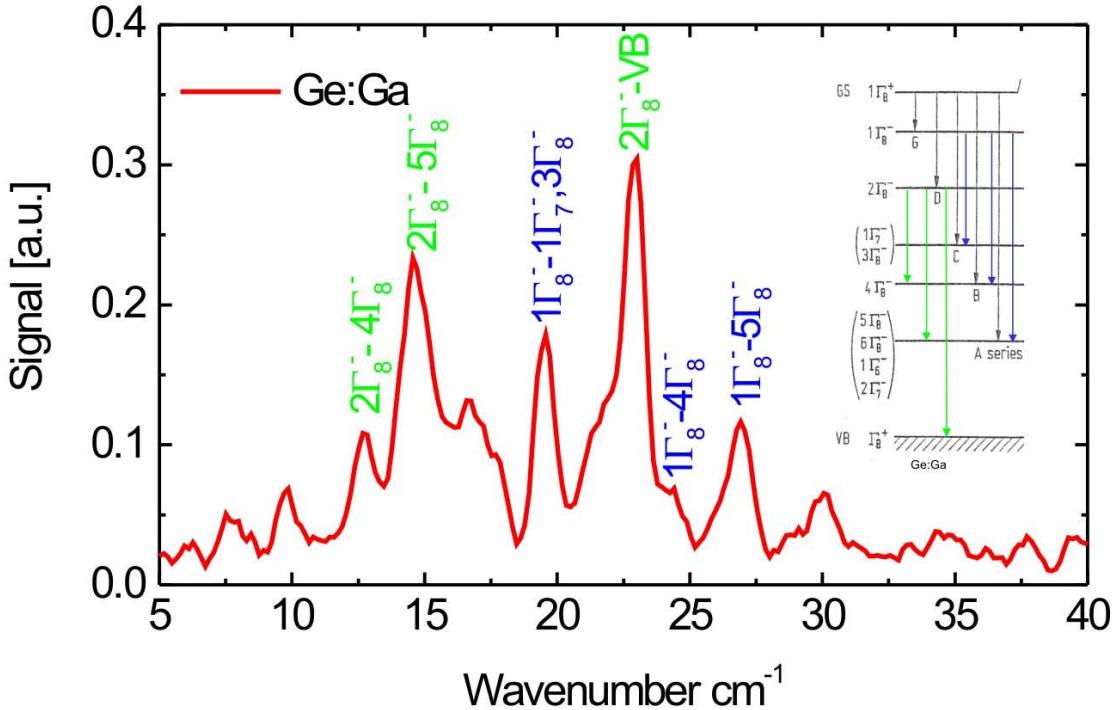




Forbidden Transitions in Ge:Ga



Photoconductivity Spectrum of Ge:Ga

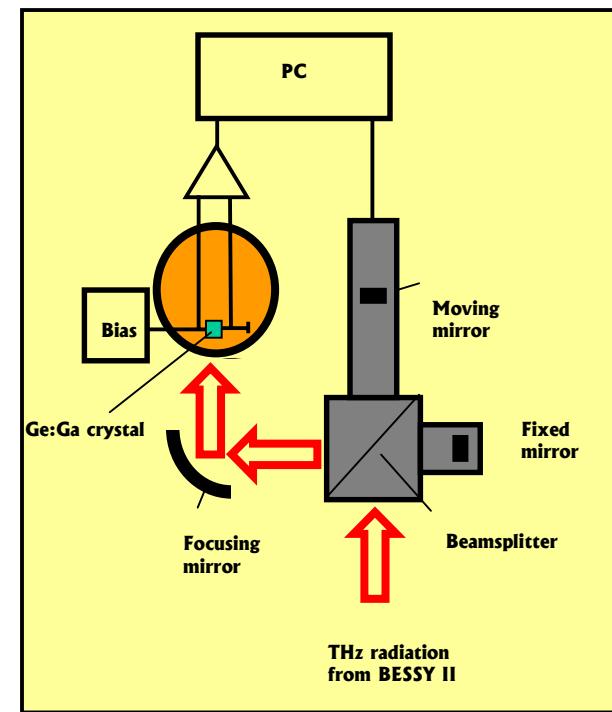


Result:

- free carriers due to impact ionization, occupy upper acceptor levels
- direct observation of forbidden (in dipole approx.) transitions
- possible due to high power of CSR

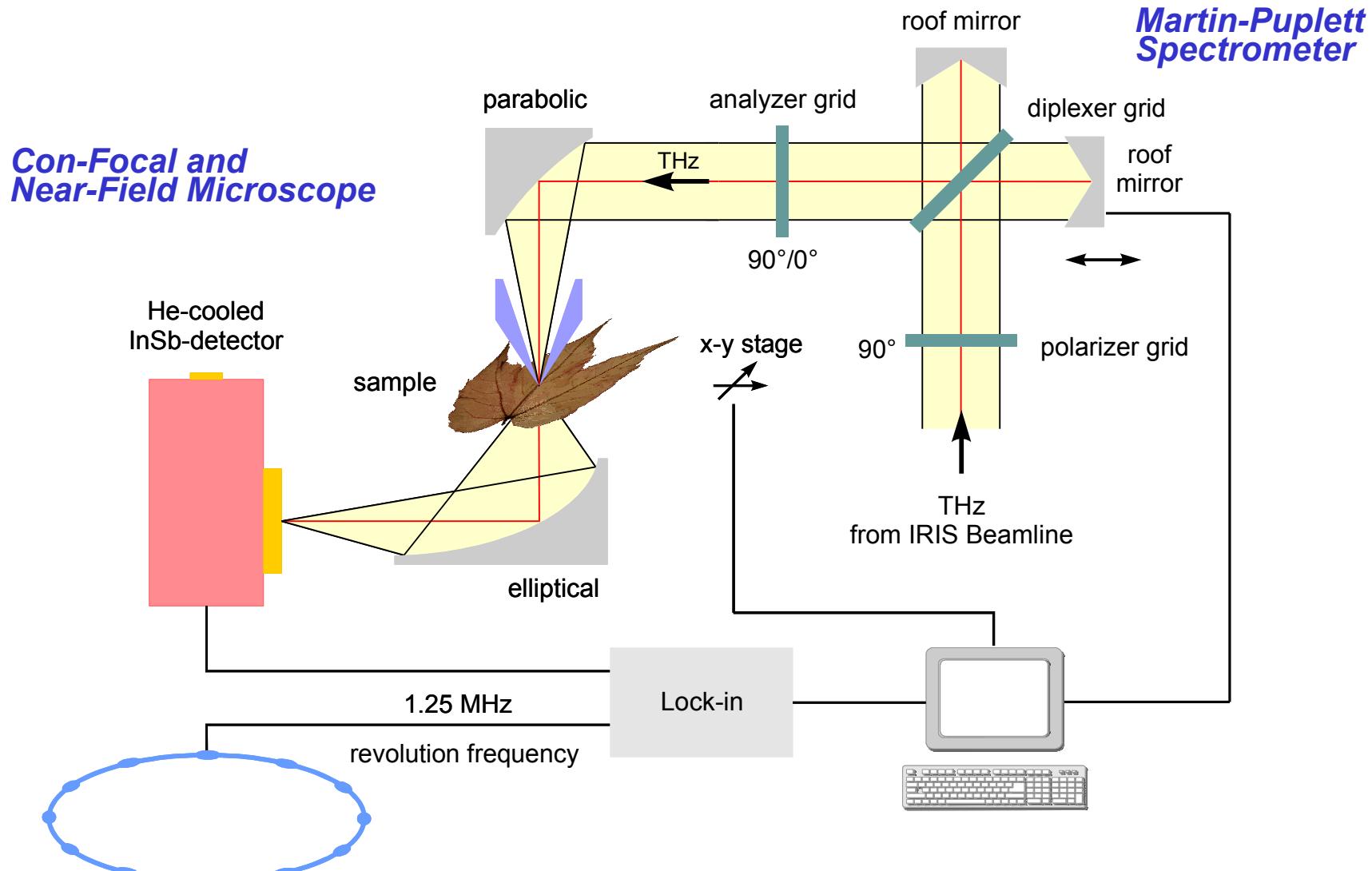
Experiment:

- Source: BESSY in CSR bursting mode
- FIR step scan FTS
- Ge:Ga, $N_d = 6 \times 10^{15} \text{ cm}^{-3}$, @ 4.5 K



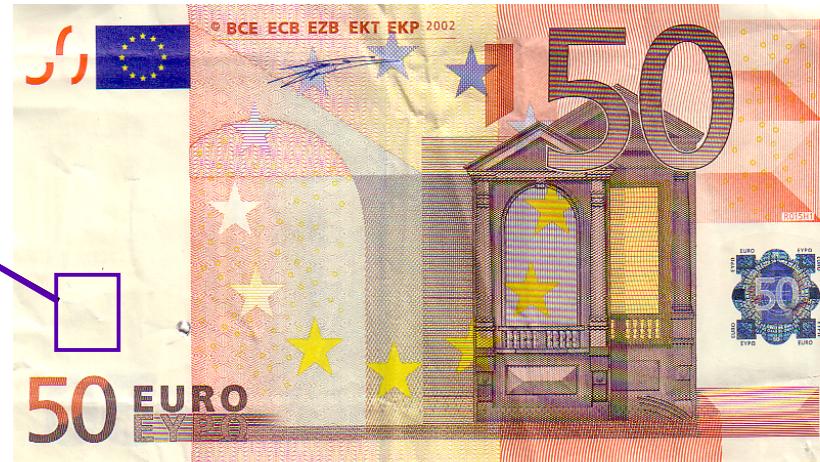


Imaging with CSR





T-Ray Image @ 0.6 THz of watermark



- reverse contrast of features in comparison to VIS image
- development of T-ray food screening methods at BESSY together with industry
- manifold applications in life and material sciences
(e.g. by other sources, D. Mittleman, Rice U)

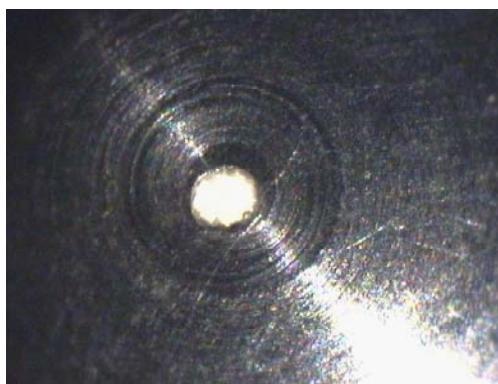




THz SNIM Probes



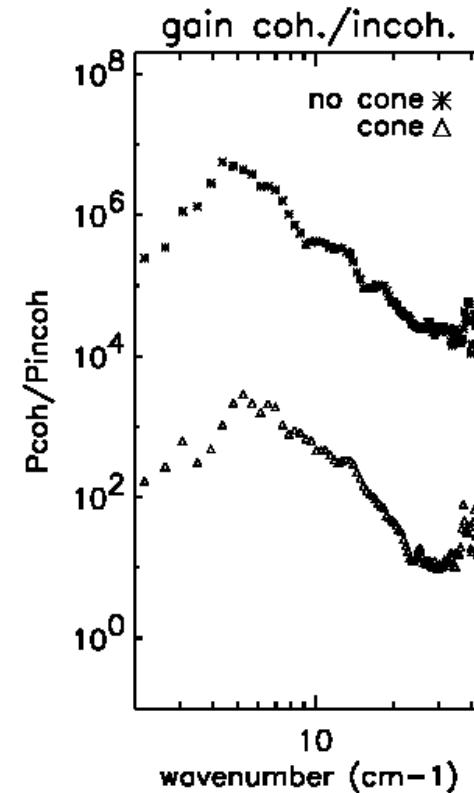
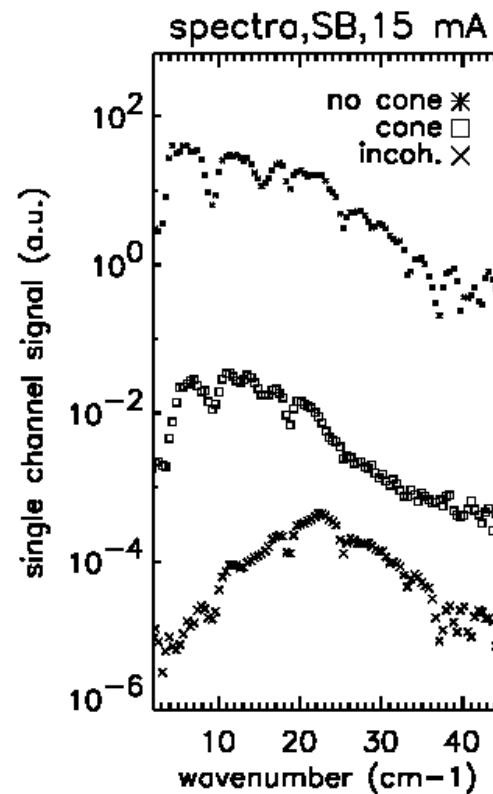
aperture cone of 200 μm diameter



co-axial aperture cone of 200 μm diameter, wire diameter is 80 μm



probe design according to Keilmann, 1995.

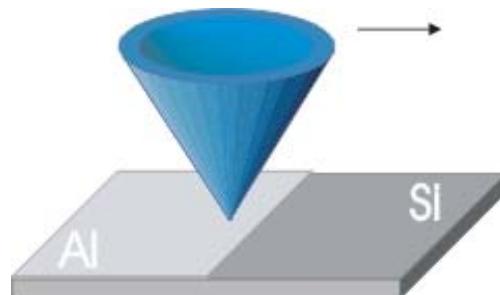
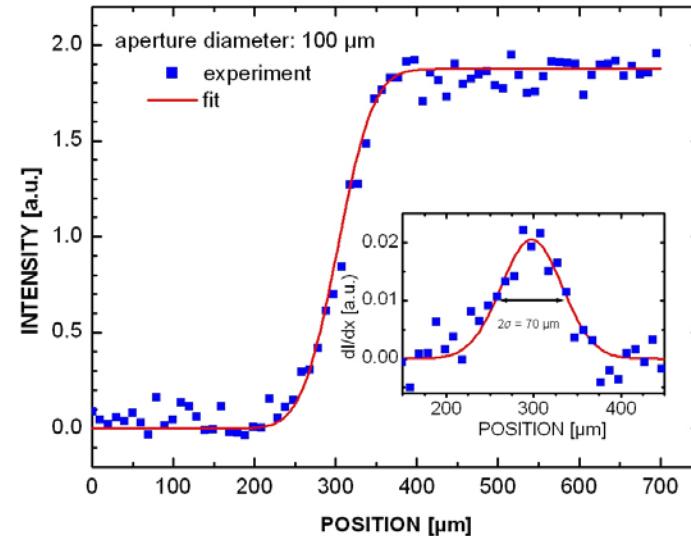
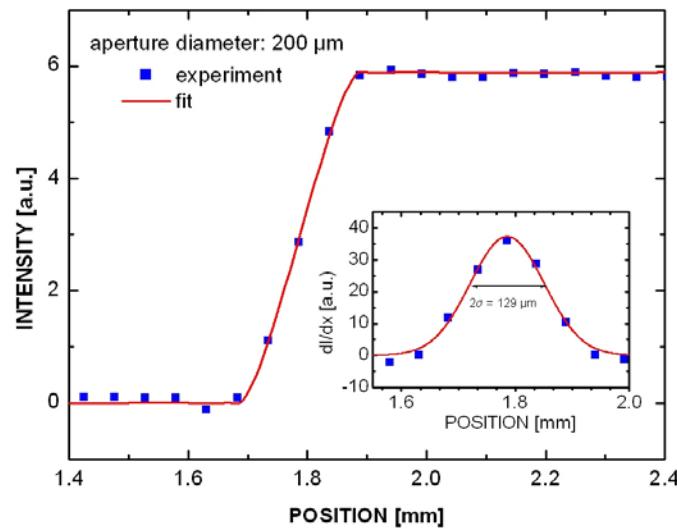


Transmittance spectra for an aperture cone of 200 μm diameter





Spatial Resolution of the THz SNIM

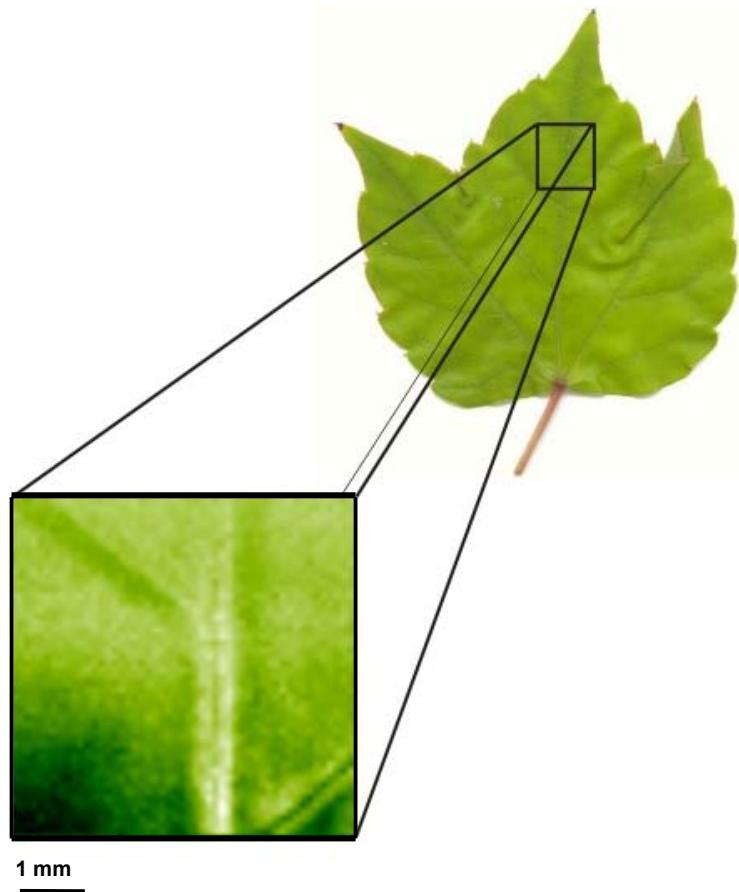
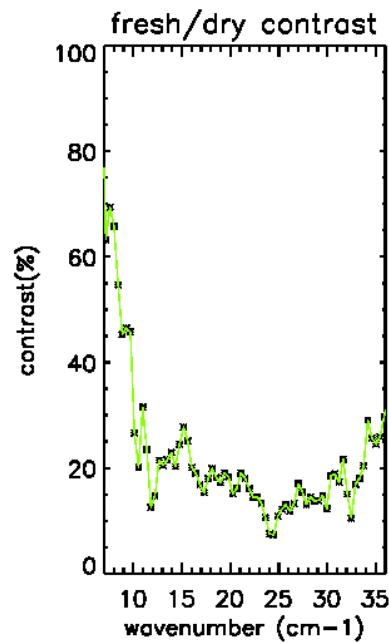
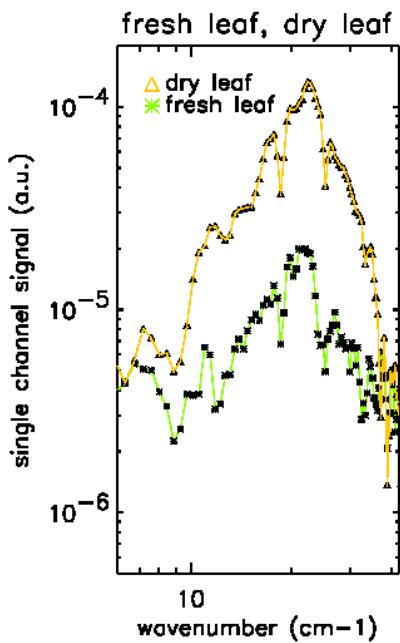


- “edge test” on Al-film on Si-substrate
- spatial resolution @ 1 mm wavelength (0.33 THz):
 - 100 µm aperture: 70 µm $\approx 1/14 \lambda$
 - 200 µm aperture: 130 µm $\approx 1/8 \lambda$
(@ 5 mm wavelength (0.066 THz): $\approx 1/38 \lambda$)





Biological Applications of THz SNIM with CSR



THz spectra of a fresh and a dried leaf.

Near-field image of a *parthenocissus* leaf
($130 \mu\text{m}$ spatial resolution).





Biological Applications of THz SNIM with CSR

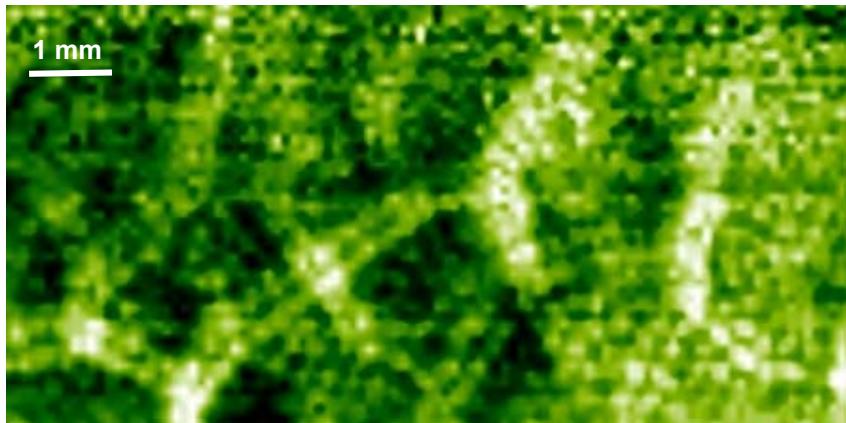


VIS- image



- VIS and THz near-field image of a laurel leaf
- spatial resolution: 130 µm
- spectral weight @ 1mm wavelength

Near-field image





Summary



Coherent FIR SR source established at BESSY:

- steady-state and bursting
- 2 - 60 cm⁻¹

Applications:

- material research (superconductor, semiconductor)
- spectral imaging (con-focal and near-field)

Outlook:

- increasing number of THz-user's proposals
- dedicated THz-port at IRIS is planned





Acknowledgements



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